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Devlopment of Tangential Injection Combustor for Micro Gas Turbine

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Mini and Micro-turbines offer advantages such as small-scale, mobile and cheap and reliable power generation, particularly for distributed power generation.They also have potential of use in combined heat and power (CHP) applications. Distributed generation is a revolutionary concept, which consists of local generation of electric, thermal or mechanical energy. Advantages of Micro Gas Turbine (MGT) include compact size and low weight per unit power, reduced cost of ownership, less number of moving parts, lower noise, multi-fuel capabilities as well as opportunities for lower emissions (in the CHP context). Parente, Mori and Croce (1) have published their design and CFD analysis of combustor for MGT. Opdyke (2) has reported development of an annular reverse-flow combustor but his work is with traditional experimental techniques without CFD analysis. Haasis (3) has described the design considerations and performance characteristics of combustors for small gas turbine engines. Andersen and Wagner (4) have reported high temperature combustor research for small gas turbine engines. The use of radial turbine and annular recuperator in the proposed micro gas turbine require compact and efficient reverse flow annular combustor. It facilitates shorter shaft length allowing close coupling of turbomachinery. This is important considering the higher RPM of small gas turbine to avoid shaft whirling. The present recuperated combustor is designed for given inlet air and exit gas temperature, airflow rate and operating pressure with a reasonable pressure drop. Annular combustor with radial gas exit near outer liner yields better pattern factor. Generally it is difficult to supply air to inner annular passage to supply air from bottom liner, however in this design there are no air injection holes in inner liner except for film cooling, thus reducing air requirement in inner annulus. Fuel injection is tangential to a hypothetical cylinder in the middle of the two liners, which may be from dome or liner, hence the name Tangential Injection Combustor.

It makes the fuel travel in helical path yielding longer residence time and higher combustion efficiency hence shorter combustor. In addition hot flame is confined within primary zone, so combustor exit temperature profile becomes uniform and life of the nozzles and turbine improves. Conical bluff body is used to stabilize kerosene flame. Nonpremix flame is used to get high stability and avoid flame flashback. Liners are cooled by film cooling and Dome is cooled by transpiration cooling.

Extensive CFD analysis was carried out initially using CFD-ACE+ to try different configurations of tangential injection design and achieve continuous ring of stabilized flame in the primary zone without overheating the liner, dome or injectors with least possible pressure drop and pattern factor of exit gas temperature. Unstructured Tetrahedral mesh is generated using CFD-GEOM for domain discretization. A 45° sector of the annular combustor was analyzed by giving cyclic boundary condition at the side faces of the model. Wall heat transfer/loss was neglected by giving zero heat flux boundary condition to walls. Radiation was also neglected because aim of the initial analysis was to fit aerodynamic design. The CFD simulations were steady state and all the domains were fluid volumes. Standard k-ε model is used for turbulence simulation. Mixture mass fraction approach was used to save time and turbulence chemistry interaction was carried out using eddy breakup model. Kerosene fuel was modeled by one-step combustion reaction of $C_{12}H_{23}$ available in the software database. Fuel was assumed to be in vaporized state when entering the combustion zone, i.e. turbulent diffusion flame was assumed, hence no atomization, two phase flow or droplet size distribution were given. First order upwind scheme was used with Algebraic Multi Grid (AMG) solver for all the equations.

Three different configurations of tangential injection design were tried namely a) fuel injection from liner with primary holes in liner b) fuel injection from liner without primary holes in liner c) Fuel injection from dome without primary holes in liner. In addition to the above the size of the flame holder and injection angle were also varied. This was done to ascertain that the flame is in the center of the two liners without hitting and heating the next injector. After getting one satisfactory aerodynamic design from the trail a configuration was frozen and analysis was carried out further to achieve satisfactory cooling of dome and liners. Positions of film cooling holes and their number were optimally selected to get the desired liner and dome cooling. Finally the number of dilution holes, their location, and their total opening area were varied to get the best possible pattern factor.

As the design intricacies increased, number of grid cells was increased to satisfactorily resolve flow, turbulence, energy and species gradients. For the finalized design, grid independence study was carried out. Figure-1 and Figure-2 show results of liner injection. Flame is lifted (detached from flame holder) due to high air velocity through injector in Figure-1. This is considered to be unstable because slight fluctuations in pressure can blowoff the flame. Figure-2 shows continuous ring of flame attached to the flame holder for another configuration. It gives highly stable flame but it may lead to severe heating of dome and injector next to each flame. Figure-8 & Figure-9 show CFD model of finalized configuration with surfaces having flow and cyclic boundary conditions. All the other surfaces are given wall boundary condition. Figure-3 containing eight mages shows variation of total temperature along the combustor axis for finalized design where injection is from dome. First image is of temperature just near the dome plate. Due to the smooth current of transpiration air, dome is cooled and because injection is from dome, no separated stream or wake of flame can revert back and heat the dome. Figure-4 and Figure-5 show variation of equivalence ratio and velocity vectors with magnitude respectively. Figure-6 and Figure-7 represent the results of grid independence study. Excellent grid independence is observed for pressure drop and exit temperature but the variation of pattern factor with number of grid cells is not regular. For coarser grid it is very high which can be accepted but after decreasing to 17.5 %, it again increases for fine grid. Hence, further investigation has to be carried out to ascertain the reasons of this behavior. For the grid independence study, species mass fraction approach was used. Temperatures at various locations in flow field were also comparatively high during grid independence study from previous simulations carried our using mixture mass fraction approach. Figures 10, 11 & 12 show Y+ values at combustor walls which are important to capture thermal and fluid dynamic boundary layer and determine wall friction and convection heat transfer coefficient. Based on the above analysis, tangential injection design is found to meet the specified performance and operational criteria.

References

1. "Micro Gas Turbine Combustion Chamber Design and CFD Analysis", Joao Parente, Giulio Mori and Giulio Croce, GT2004-54247, ASME Turbo Expo 2004
2. "Development of an Annular Reverse-Flow Combustor" George Opdyke, Jr SAE=444E

3. "Design Considerations and Performance Characteristics of Combustors for Small Gas Turbine Engines", J. M. Haasis, AiResearch Manufacturing Co. of Arizona, A Division of The Garrett Corp., SAE-444-B
4. "Advanced High Temperature Combustor Research for Small Gas Turbine Engines", Richard Andersen and David Wagner, Curtiss-Wright Corp., SAE 680446

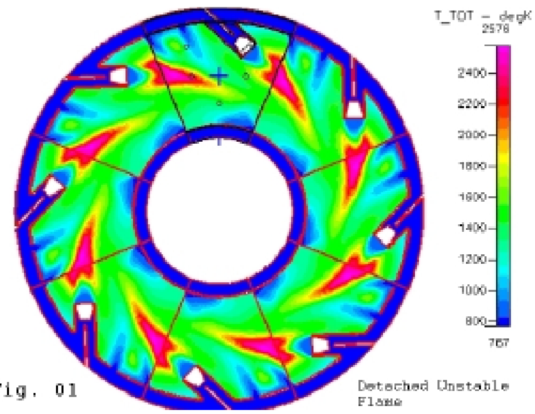

Fig. 01

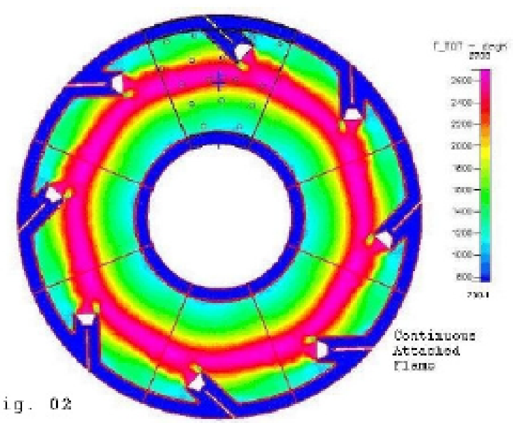

Fig. 02

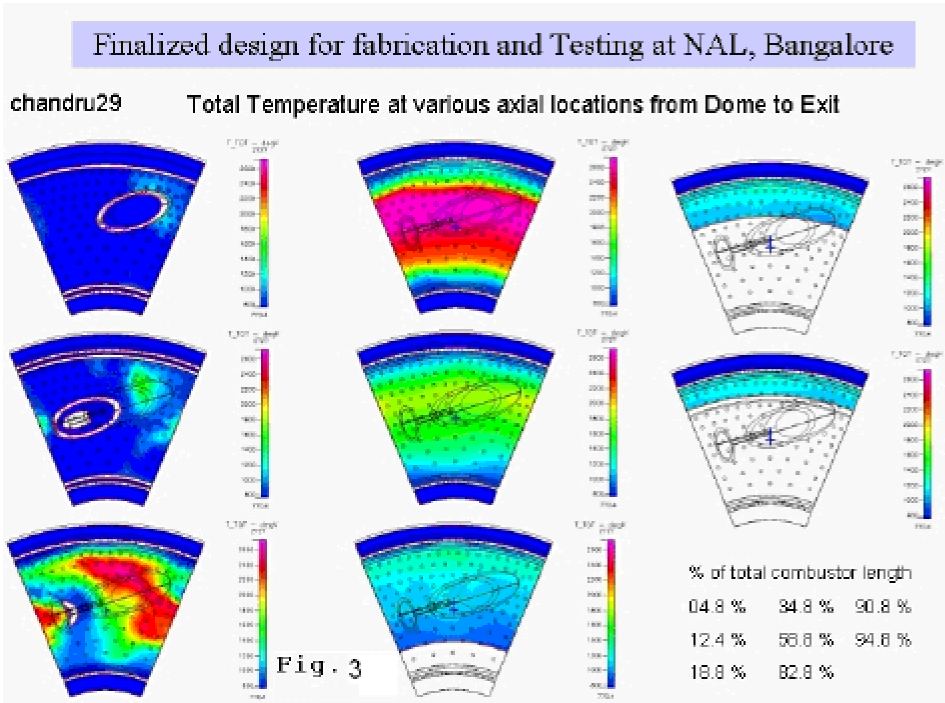
Finalized design for fabrication and Testing at NAL, Bangalore
chandru29
Total Temperature at various axial locations from Dome to Exit
% of total combustor length
04.8 %
34.8 %
90.8 %
12.4 %
58.8 %
94.8 %
18.8 %
82.8 %

Fig. 3

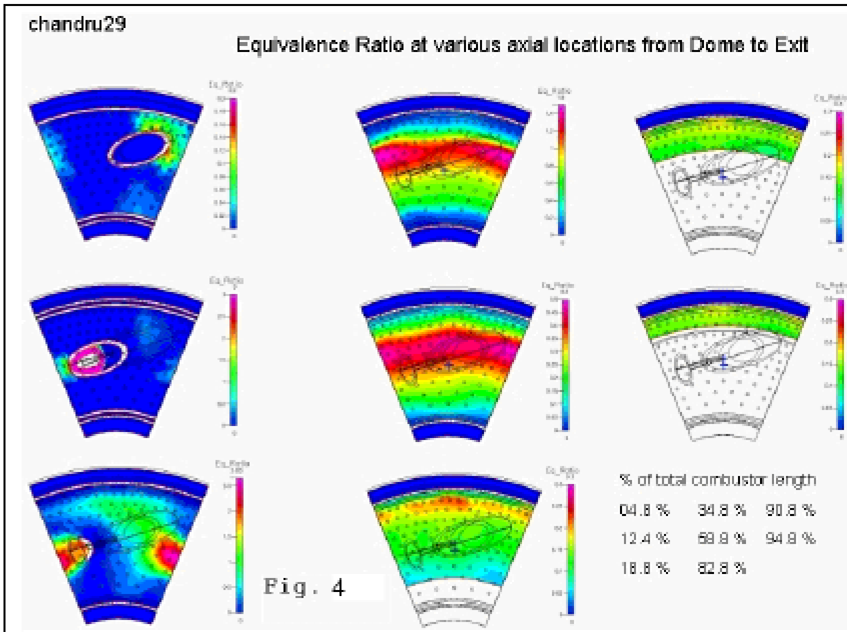
chandru29
Equivalence Ratio at various axial locations from Dome to Exit
% of total combustor length
04.8 %
34.8 %
90.8 %
12.4 %
58.8 %
94.8 %
18.8 %
82.8 %

Fig. 4

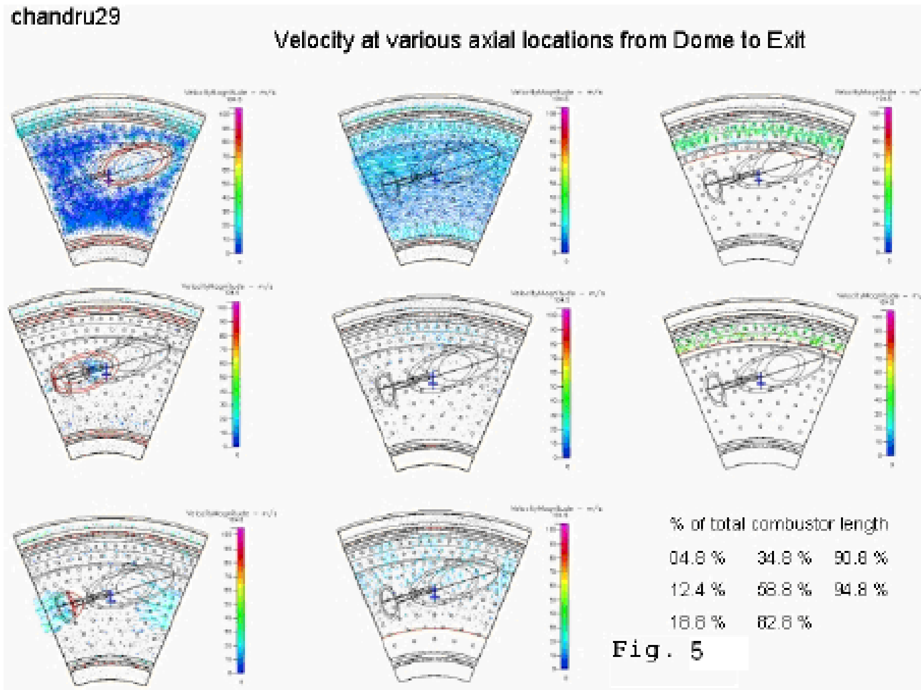
chandru29
Velocity at various axial locations from Dome to Exit
% of total combustor length
04.8 % 34.8 % 90.8 %
12.4 % 58.8 % 94.8 %
18.8 % 82.8 %

Fig. 5

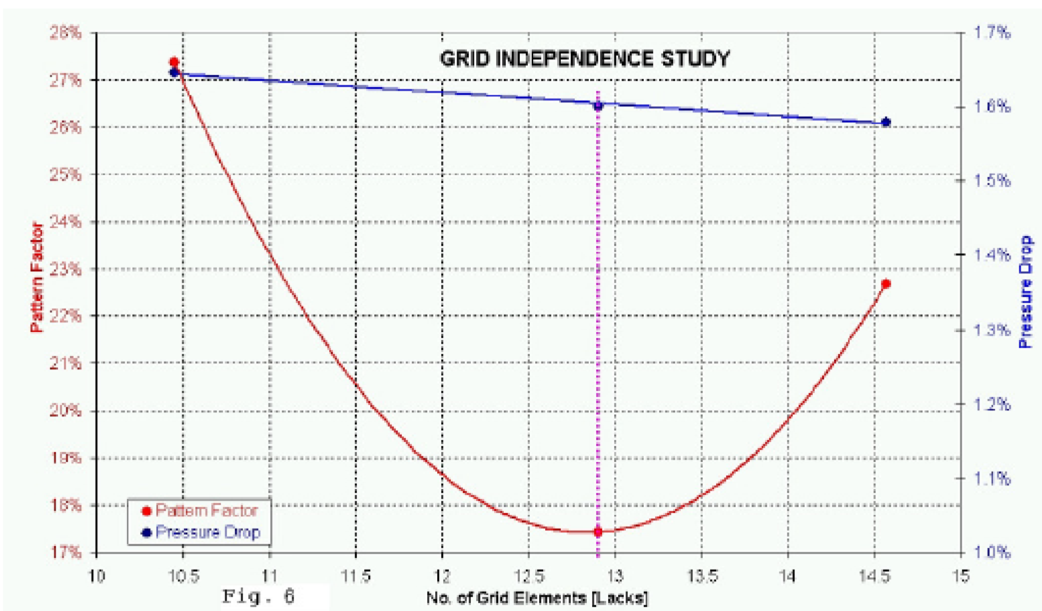
GRID INDEPENDENCE STUDY
Pattern Factor
Pressure Drop
No. of Grid Elements [Lacks]

Fig. 6

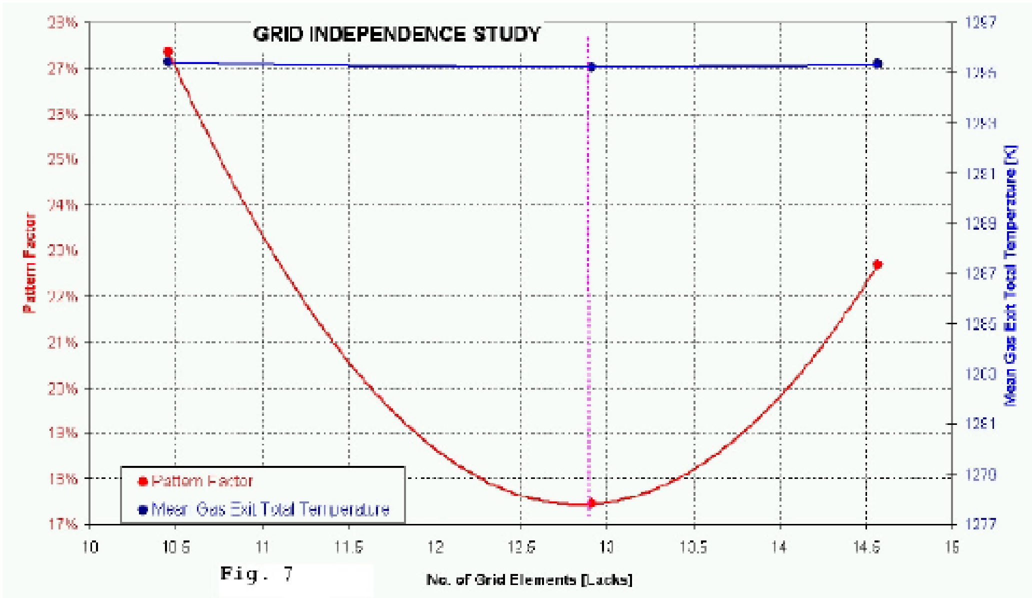

Fig. 7

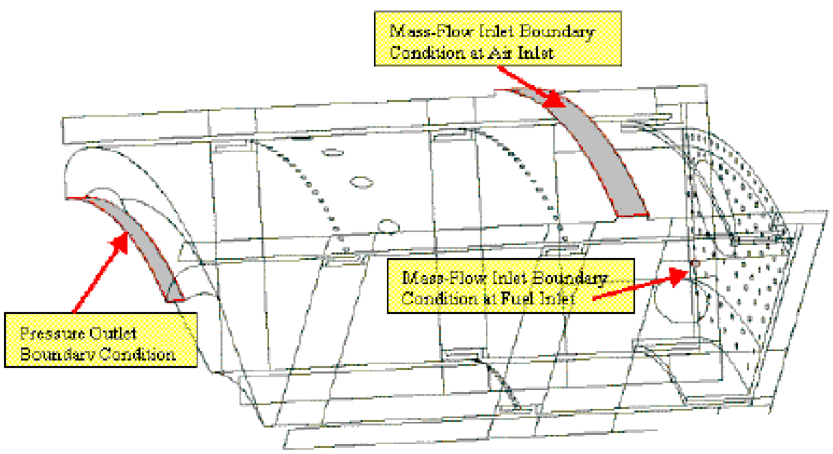

Fig. 8 -- Mass-Flow Boundary Condition

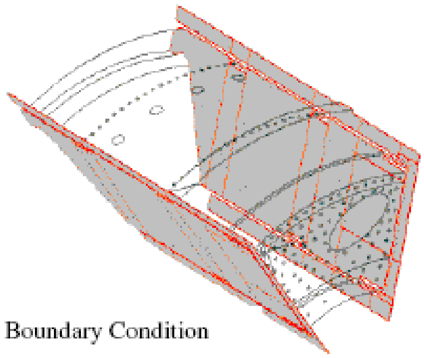

Fig. 9 -- Cyclic Boundary Condition

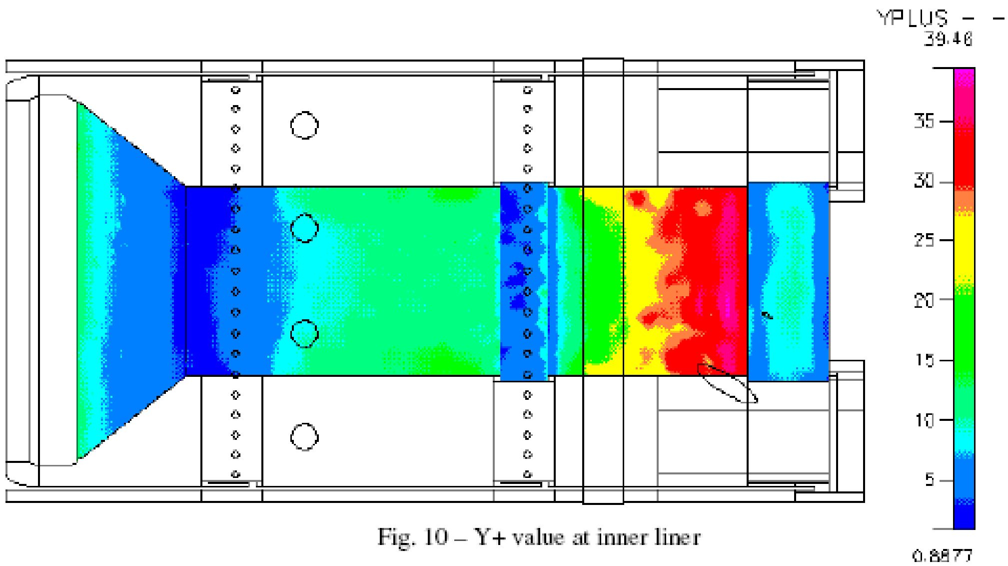

Fig. 10 – Y+ value at inner liner

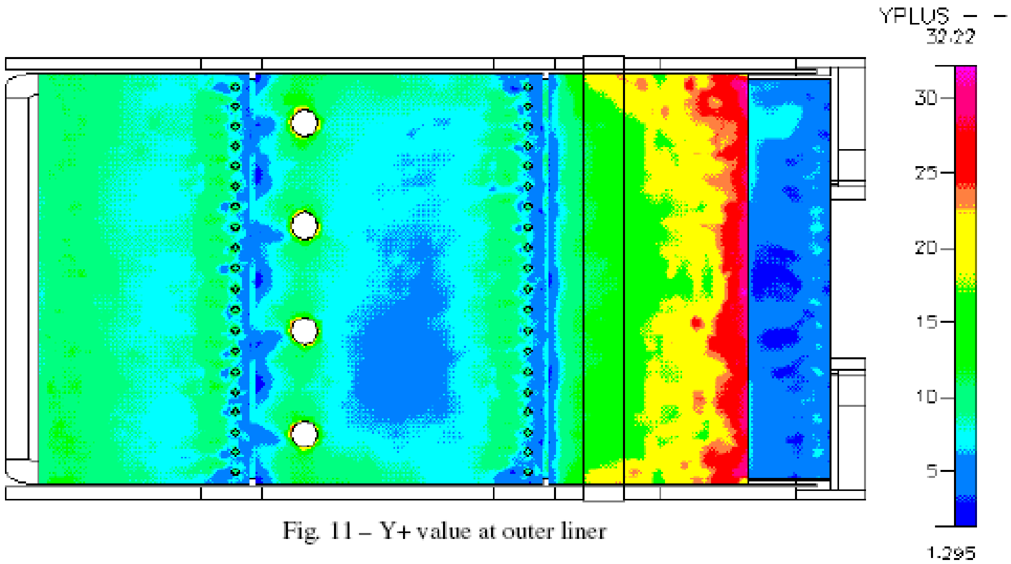

Fig. 11 – Y+ value at outer liner

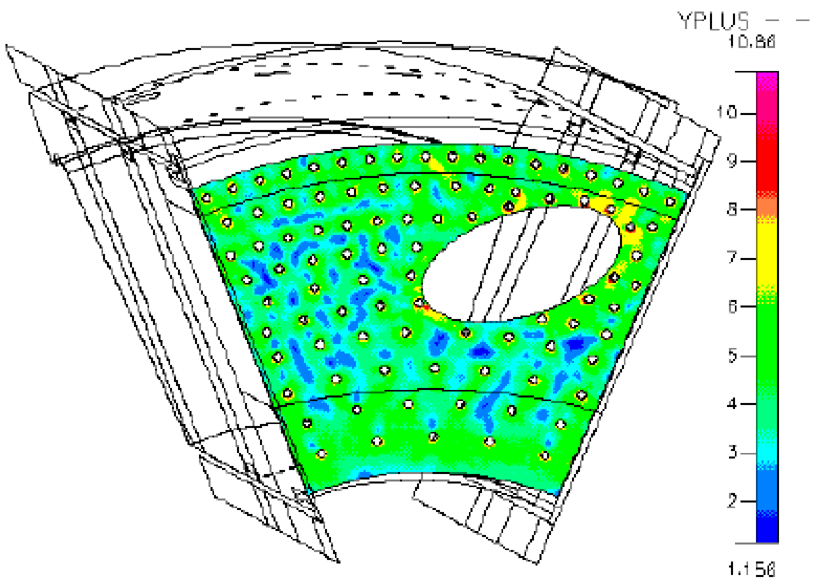

Fig. 12 – Y+ value at dome